frontiers in
HUMAN NEUROSCIENCE

SUPPLEMENTARY MATERIAL
published: 13 April 2010
doi: 10.3389/fnhum.2010.00031

# Time course of target recognition in visual search

***Andreas Kotowicz[1,2]*, Ueli Rutishauser[1] and Christof Koch[1,3]***

[1] *Computation and Neural Systems, California Institute of Technology, Pasadena, CA, USA*
[2] *Institute of Neuroinformatics, University of Zurich and ETH Zurich, Zurich, Switzerland*
[3] *Division of Biology and Division of Engineering and Applied Science, California Institute of Technology, Pasadena, CA, USA*

Edited by: Maurizio Corbetta, Washington University, USA

Reviewed by: Martin Paré, Queen's University, Canada
Matt Peterson, George Mason University, USA
Miguel Eckstein, University of California, Santa Barbara, USA

*Correspondence: Andreas Kotowicz, Institute of Neuroinformatics, University of Zurich and ETH Zurich, Winterthurerstrasse 190, 8057 Zurich, Switzerland.e-mail: kotowicz@ini.phys.ethz.ch

Received: 06 August 2009; paper pending published: 17 October 2009; accepted: 25 March 2010; published online: 13 April 2010.Citation: Kotowicz A, Rutishauser U and Koch C (2010) Time course of target recognition in visual search. *Front. Hum. Neurosci.* **4**:31. doi: 10.3389/fnhum.2010.00031



## DATA ANALYSIS – STATISTICAL TESTS USED

We used the following statistics:

(i) A two-tailed two-sample *t*-test ($\alpha = 5\%$) was used to compare performance to chance. We also used this test to compare fixations durations, since they are normally distributed.
(ii) To check if performance changed as a function of fixation duration or trial duration, we used a one-way analysis of variance (ANOVA). The independent variable was binned time (see below). Each subject contributed one value (mean performance of all trials) to each bin.
(iii) We checked for differences in correct versus incorrect trials using a two-way analysis of variance (2wANOVA) with no interactions. The independent variable was time or distance; the two grouping variables were single trial performance (correct/incorrect) and subject number. We report the *p*-value associated with the correct/incorrect grouping variable which represents a true within-subject comparison (within-subject ANOVA).
(iv) We used a two-sided Wilcoxon rank sum test ($\alpha = 5\%$) to compare saccade amplitudes (which are gamma distributed).

If not stated otherwise, *p*-values refer to above tests (referred to by *t*-test, ANOVA, 2wANOVA or rank sum).

## DATA ANALYSIS – PERFORMANCE AND CHANCE PERFORMANCE

For each type of experiment, we consider how the performance of the subjects changes as a function of time. We bin the times and calculate the mean performance over all subjects for each bin. To compare this to chance levels, we randomly assign subjects' answers to one of the grid positions and calculate the mean over the "chance subjects". Chance levels are always represented by yellow bars throughout all figures. In addition, we confirmed that subjects have a coherent concept of confidence by looking at their performance as a function of confidence. As expected, trials were correct most of the time when subjects were confident, whereas only 50% and 9% of trials were correct when subjects responded "maybe" and "guessing" (with chance level corresponding to 9%).

## DATA ANALYSIS – CONFIDENCE

Subjects were asked to indicate their confidence on a scale of 1 (guessing), 2 (maybe) or 3 (highly confident) by button press. Wherever we report confidence, we present the mean confidence rating for all trials, regardless of whether the answer was correct or incorrect. In addition, we calculated confidence considering correct trials only. However, except for an increase in baseline confidence, we did not find any significant differences and thus do not report this value.

## EXACT TIMING OF STIMULUS ONSET AND EYE MOVEMENTS – DETAILS

The implementation of the Psychophysics Toolbox Version 3 (PTB-3) we used allows the user to read out the beam position of the CRT monitor (through OpenGL). Whereas previous PTB versions included commands to draw a stimulus at the next refresh cycle, it is now possible to know *when* the stimulus actually *appeared* on the screen. There is a crucial difference between these two cases: in the former case a stimulus drawing command was put into the queue of to-be-executed calls. Since a CRT monitor only refreshes every $X$ ms it was unknown when exactly the monitor refresh occurred (on average after $X/2$ ms). With the new PTB-3 implementation, it is possible to request a timestamp from the graphics card once the refresh happened.

**Figure 3** (main text) illustrates the detailed eyetracker and monitor time interaction. The time $t_{25}$ between stimulus onset and mask onset can be directly accessed from the PTB-3 as mentioned above. $t_{\text{tracker}}$ is known from the eyetracker recording data. What is unknown is the relationship of these two independent measures since they are both done on independent computers. Therefore it is necessary to determine the time $t_{12}$ as accurately as possible in order to know when the stimulus was presented relative to the recorded eye

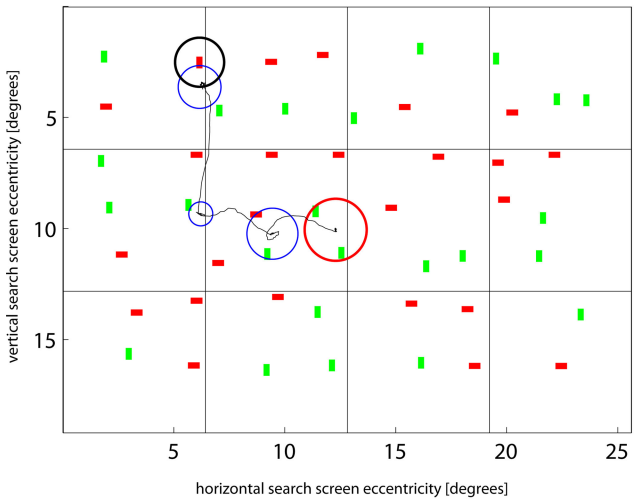


**FIGURE S1 | Same as Figure 1, this time showing the 4 × 3 grid.** At the end of every trial subjects were told that they correctly identified the target, if they fixated an item that was located inside the same quadrant as the target. In the trial shown here, the quadrant containing the target is located in the upper left corner.

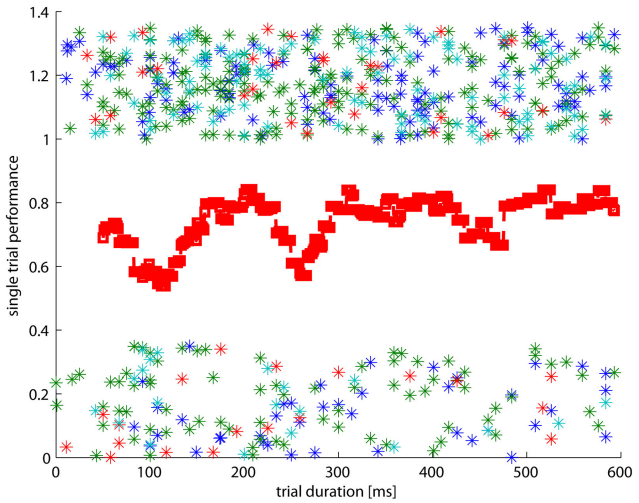


**FIGURE S3 | Illustration of the trial-by-trial performance for all subjects for the fixation control task (Experiment 3, without mask).** The target was always located within 5° of the fixated center of the screen. Notation as in **Figure S2**. Note the much higher density around 1 for all 4 subjects (blue, green, red and turquoise stars). See also Figure 6C for comparison.

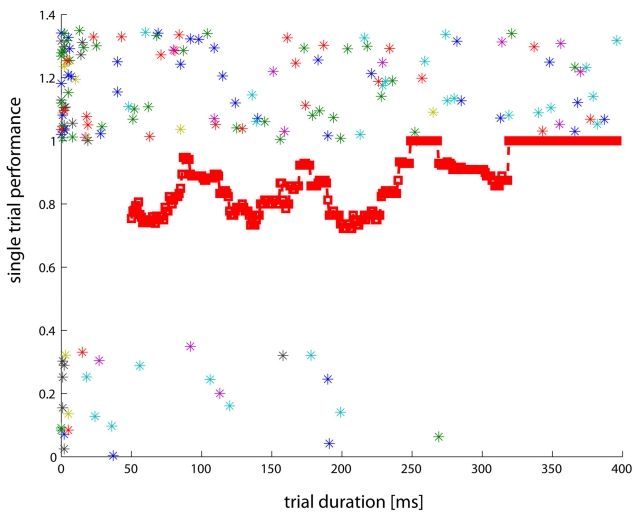


**FIGURE S2 | Illustration of the trial-by-trial performance for all subjects for the main search task (Experiment 1, compare with Figure 4).** Mean performance (red, 50-ms window) was different from chance (8.3%) independent of fixation duration. Stars mark each correct (1) or incorrect (0) trial for each subject. Random noise (0–0.35) was added to each performance value to allow visualization of the distribution. Note the higher density of points around 1 (correct) even for very short trial duration. Each color is a different subject.

movement data: $t_{12} = t_{\text{tracker}} - t_{25} - t_{56}$. Knowing the first two arguments we only need to find $t_{56}$, which is the time which passes between showing the mask and sending the "eyetracker stop" command. This time interval is limited by how long it takes to flip the graphics buffer, since the mask onset command will only return a timestamp once the buffer has been flipped. The eyetracker stop timestamp is sent out instantaneously afterwards. We measured the time it takes to draw the stimulus and flip the buffer as approximately 0.1 ms using PTB-3. This time is very short compared to the time it takes to wait until flipping the buffers occurs (on the average $X/2$ ms, on our setup 4 ms) once we have requested this operation. $t_{56}$ can therefore be approximated to be between 0 and 1 ms. Setting $t_{56} = 0$ ms will result in overestimating the time the subjects sees the screen by a maximum of 1 ms. Therefore we are able to match stimuli presentation and eye movements with an accuracy of 1 ms.

## TASKS – DETAILED INSTRUCTIONS

Subjects were given the following written instructions (depending on the experiment):

### MAIN EXPERIMENT (EXPERIMENT 1)

At the beginning of each trial, a search target (horizontal or vertical bar in either red or green) will be shown at the center of the screen. Your task is to remember this item and find it as fast as possible in the following screen. After the target a small cross appears at the center of the screen. If you look at it, the trial starts automatically. After the cross disappears a screen full of bars will appear. Now try to find the target as quickly as possible! Once you found the target, keep looking at it until the trial terminates. Some trials will terminate before you've located the target. In either case try to indicate where you believe the target was in the part that follows. Immediately after the trial you might notice a screen full of red and green bars. You don't need to pay attention to it! It disappears very quickly and you'll always be asked to tell where you have seen the target. In order to start the confirmation you have to look at the central cross. Afterwards, please look at the location you believe the target was at. Once this is done you will be asked: "How sure are you about your choice?". Your choices are: 1 = guessing, 2 = maybe, 3 = confident. Please press the appropriate number on the keyboard. This ends the trial. You will get feedback, indicating whether

your choice was right or wrong and a new trial begins. First you will do a short version of the task (20 trials), after which any remaining questions about the task can be clarified.

**BUTTON PRESS (EXPERIMENT 2)**

At the beginning of each trial, a search target (horizontal or vertical bar in either red or green) will be shown at the center of the screen. Your task is to remember this item and find it as fast as possible in the following screen. After the target a small cross appears at the center of the screen. If you look at it, the trial starts automatically. After the cross disappears a screen full of bars will appear. Now try to find the target as quickly as possible! Once you found the target, press the "0" key and the trial terminates. Immediately after the trial you might notice a screen full of red and green bars. You don't need to pay attention to it! It disappears very quickly and you'll always be asked to tell where you have seen the target. In order to start the confirmation you have to look at the central cross. Afterwards, please press the button (1–9) of the location you believe the target was at. Once this is done you will be asked: "How sure are you about your choice?". Your choices are: 1 = guessing, 2 = maybe, 3 = confident. Please press the appropriate number on the keyboard. This ends the trial. You will get feedback, indicating whether your choice was right or wrong and a new trial begins. First you will do a short version of the task (20 trials), after which any remaining questions about the task can be clarified.

**FIXATION CONTROL (EXPERIMENT 3)**

At the beginning of each trial, a search target (horizontal or vertical bar in either red or green) will be shown at the center of the screen. Your task is to remember this item and find it as fast as possible in the following screen. After the target a small cross appears at the center of the screen. If you look at it, the trial starts automatically. After the cross disappears a screen full of bars will appear for a very short time. During this time you need to make sure that your gaze is still pointing on the center of the screen. Should you move your eyes away from the center, the screen will blank and a message "Timeout" will be displayed. So please try to keep your eyes as steady as possible. Immediately after the trial you might notice a screen full of red and green bars. You don't need to pay attention to it! It disappears very quickly and you'll always be asked to tell where you have seen the target. In order to start the confirmation you have to look at the central cross. Afterwards, please look at the location you believe the target was at. Once this is done you will be asked: "How sure are you about your choice?". Your choices are: 1 = guessing, 2 = maybe, 3 = confident. Please press the appropriate number on the keyboard. This ends the trial. You will get feedback, indicating whether your choice was right or wrong and a new trial begins. First you will do a short version of the task (20 trials), after which any remaining questions about the task can be clarified.